W Mass Measurement Experience at CDF

Chris Hays

Duke University

TeV4LHC Workshop

10/21/05

Lessons for the LHC

CDF Run 2 Uncertainties

Tower removal:

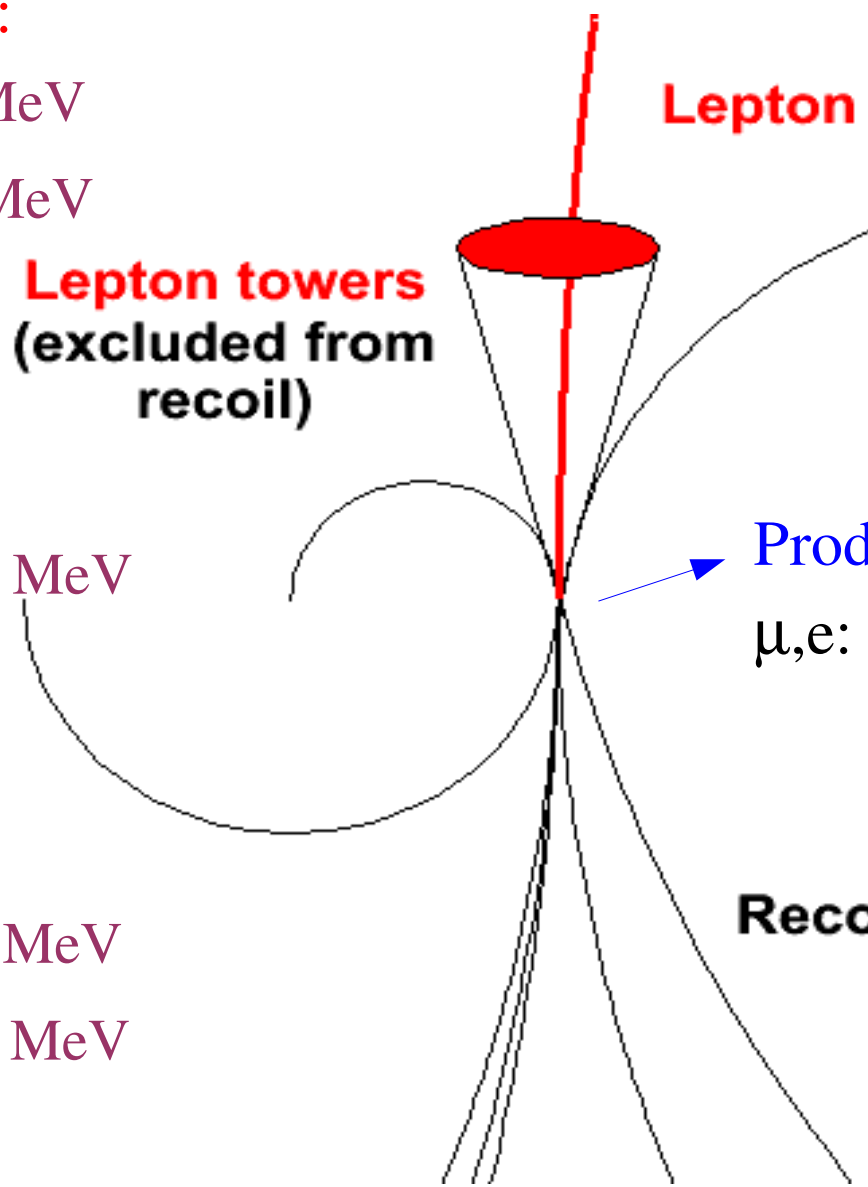
μ: $\delta m_W = \pm 10$ MeV

e: $\delta m_W = \pm 20$ MeV

Scale and resolution:

μ: $\delta m_W = \pm 30$ MeV

e: $\delta m_W = \pm 70$ MeV



Transverse mass fit

Backgrounds:

μ,e: $\delta m_W = \pm 20$ MeV

Production and decay model:

μ,e: $\delta m_W = \pm 30$ MeV

CDF RUN II
PRELIMINARY

Statistics:

μ: $\delta m_W = \pm 50$ MeV

e: $\delta m_W = \pm 45$ MeV

Scale and resolution:

μ,e: $\delta m_W = \pm 50$ MeV

CDF Event Generation and Simulation

Precision of few parts in 10^4 requires detailed model of detector interactions

Use custom simulation to achieve necessary event simulation rate

Muons: dE/dx energy loss in silicon
multiple Coulomb scattering
track resolutions -- effects of constraining to beam

This talk

Electrons: bremsstrahlung cross section, y spectrum (E: ~0.5 - 50 GeV)
conversion cross sections, y spectrum (E: ~0.01 - 50 GeV)
calorimeter response
energy loss in solenoid, longitudinal leakage

See DØ talk

Some effects must be determined with data:

Tracker alignment

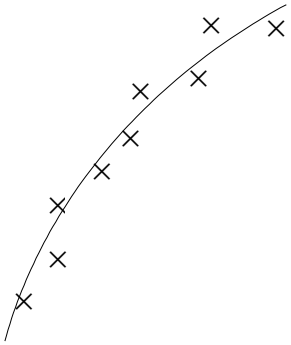
Calorimeter nonlinearity

Theory: See W/Z production theory talk

CDF Muon Momentum Calibration

Central Outer Tracker used to determine momentum

* *96 measurement layers, each with resolution ~140 μm*
* *$\delta p_T/p_T \sim 0.15\%\ p_T$ (2.4 GeV for p_T = 40 GeV)*
* *Constrain tracks to beam line to improve resolution*



Strategy:

* *Understand tracker nonuniformities*

  Determine alignment of measurement wires

× beam line

* *Calibrate momentum scale with high-statistics resonances*

  J/ψ:

  Very high statistics, can study scale as function of mean curvature

  Low momentum tracks require detailed understanding of energy loss

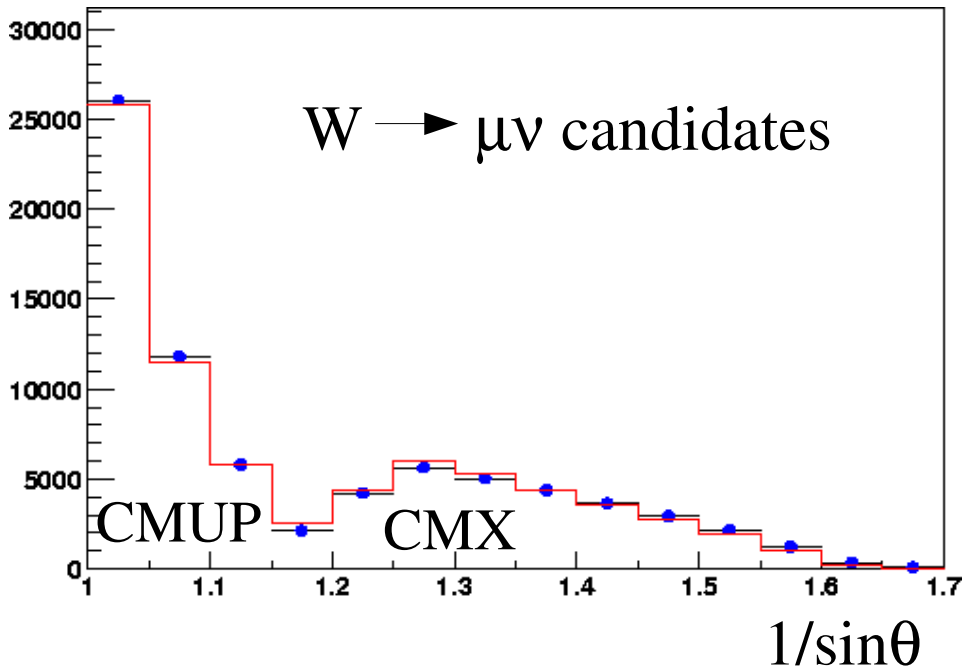
  Υ*(1s):*

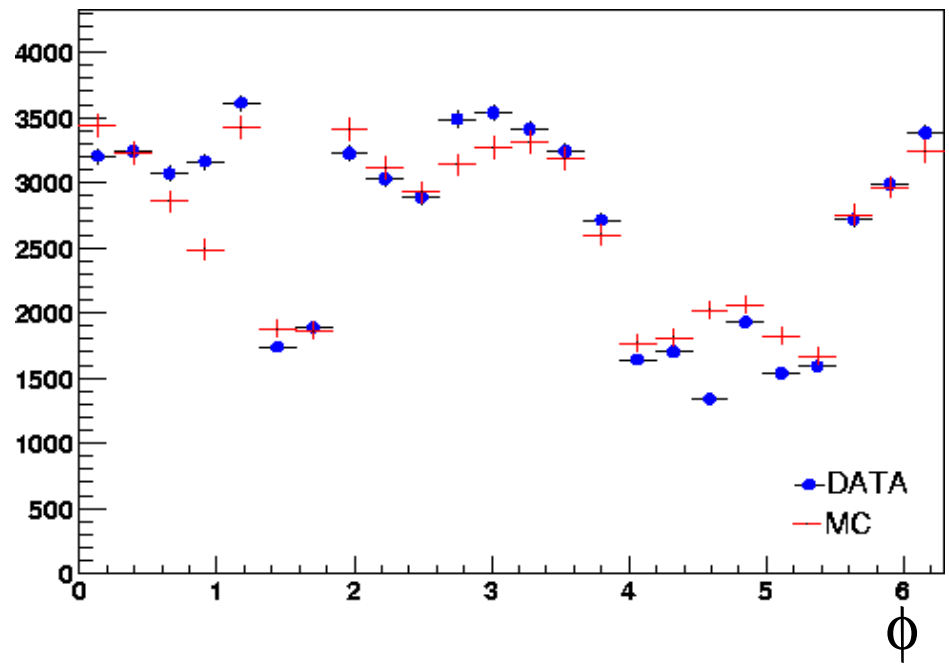
  Prompt decays allow test of beam constraint

COT Alignment

Tracker uniformity important for W mass measurement

Muon chamber fiducial acceptance highly non-uniform:



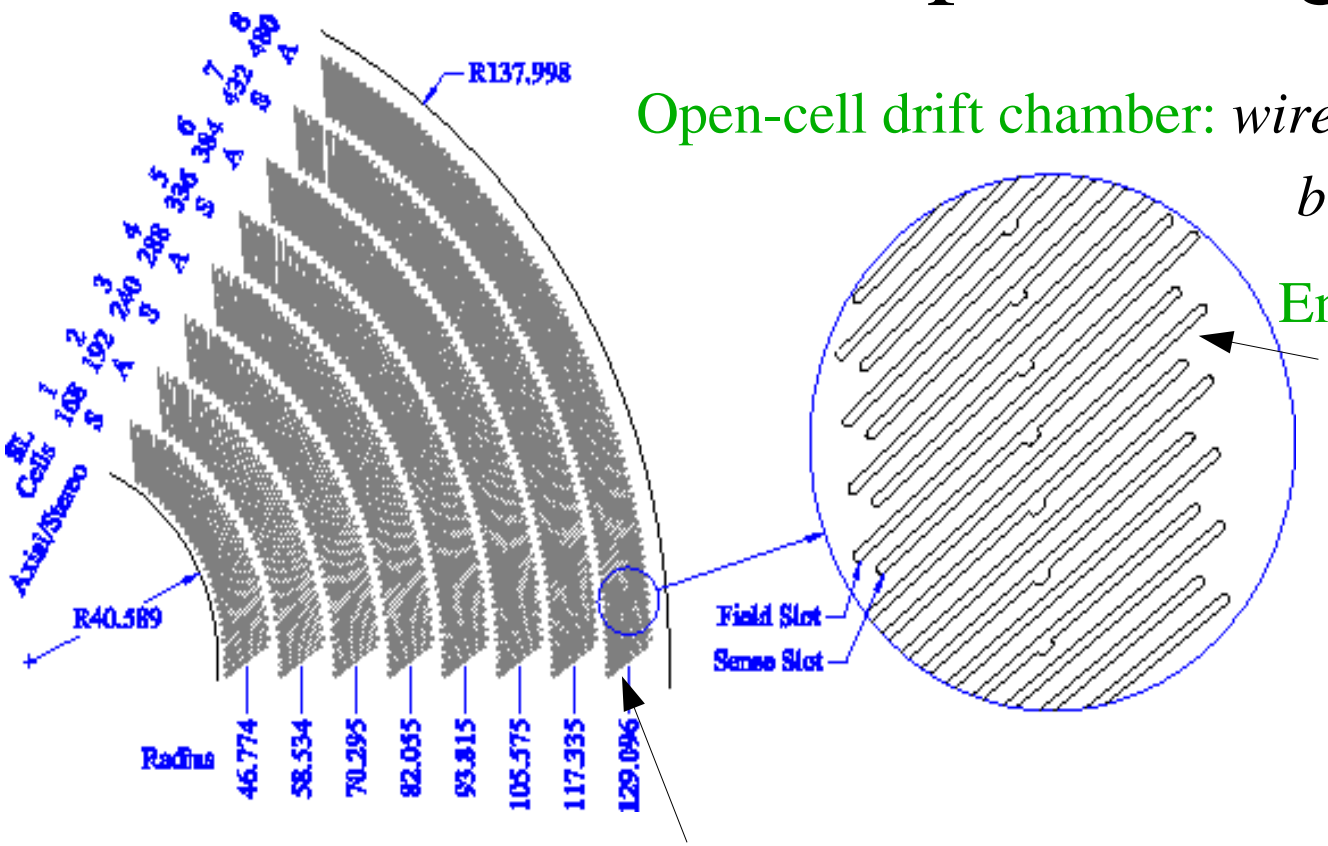


Track momentum non-uniformity could affect calibration

* difference in *W* vs *J/ψ* fiduciality: bias in *W* mass fit

* difference in muon vs electron fiduciality: *W* → eν vs *W* → μν differences

COT Endplate Alignment



Open-cell drift chamber: *wires strung under tension between two endplates*

Endplate cell positions measured to ~25 μm for a region in ϕ

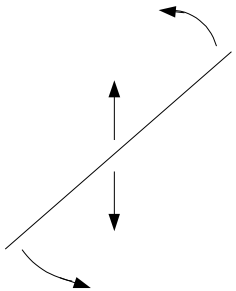
large (~100 μm) residual variations as a function of ϕ

Requires cell-to-cell alignment

8 "superlayers" of 12 wires each

Endplate cell displacement model

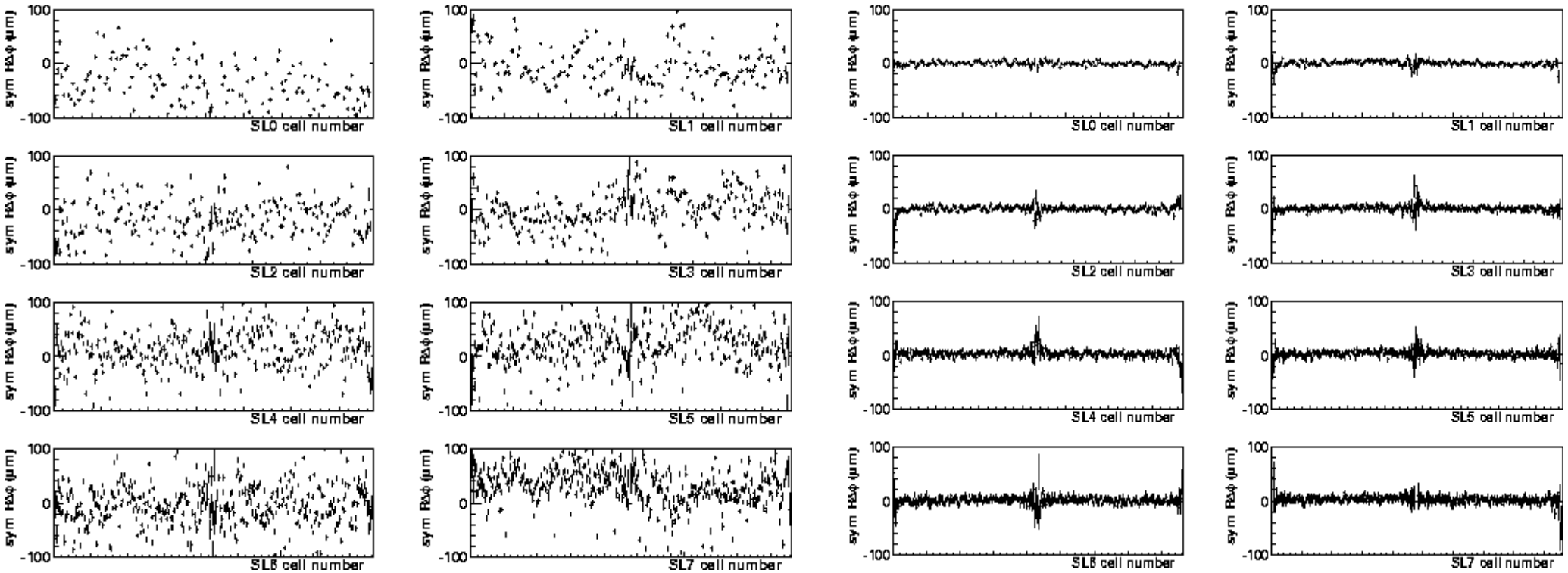
* Cell tilts, azimuthal shifts
* Separately fit shifts for each endplate



COT Endplate Alignment

Determine cell tilts, shifts using cosmic data

* Fit both legs as a single "dicosmic"
* Use hit residuals to determine displacement



Before

After

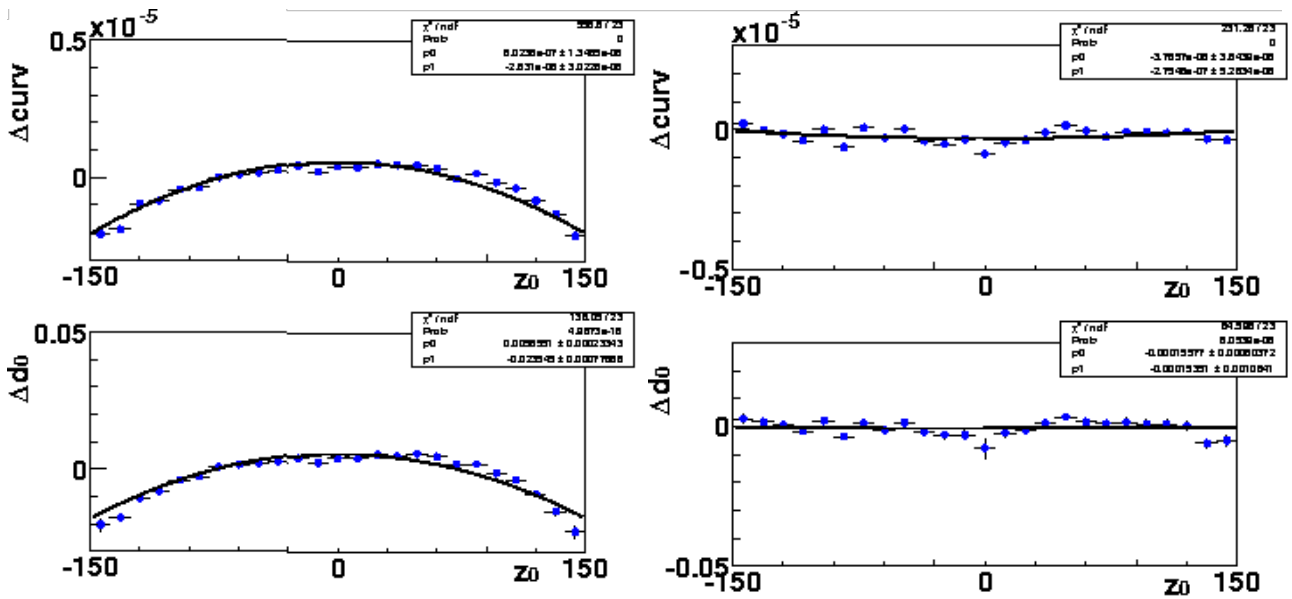
Component of cell shifts symmetric between endplates

* ±~100 μm variations reduced to <10 μm

COT Wire Alignment

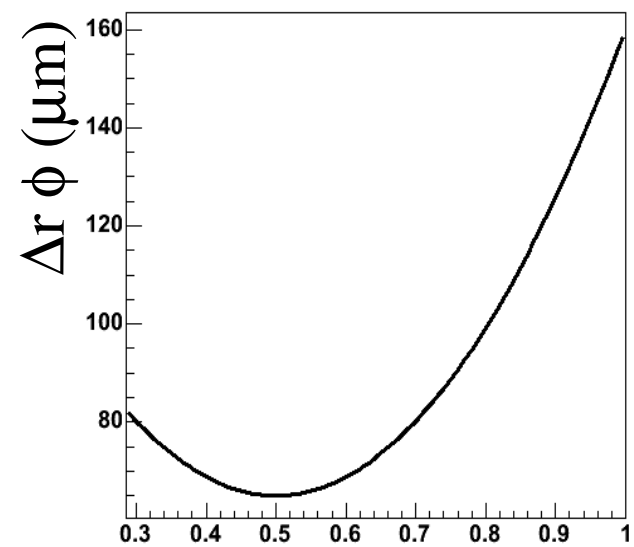
Wires have sag, electrostatic deflection between endplates

* Start with theoretical calculations
* Constrain other deflections using difference in parameters of two cosmic legs as function of z



Before

After



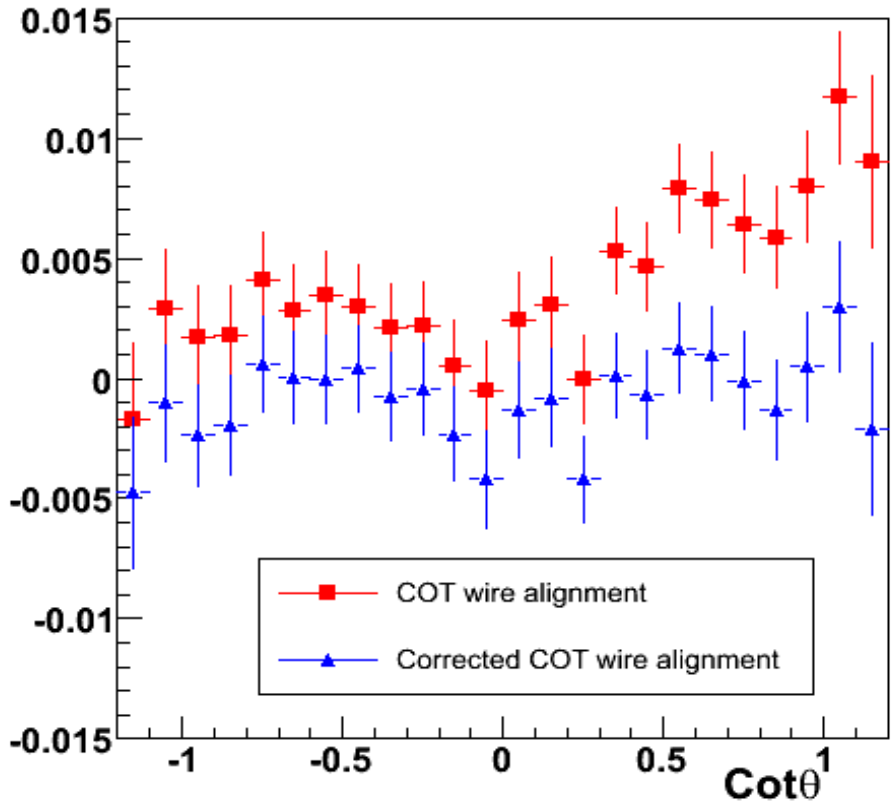
ρ

Parametric correction

$$\Delta r\phi = (a + b\rho + c\rho^2)(1-z^2), \quad \rho = r/R_{COT}, \; z = z/(L_{COT}/2)$$

COT Alignment

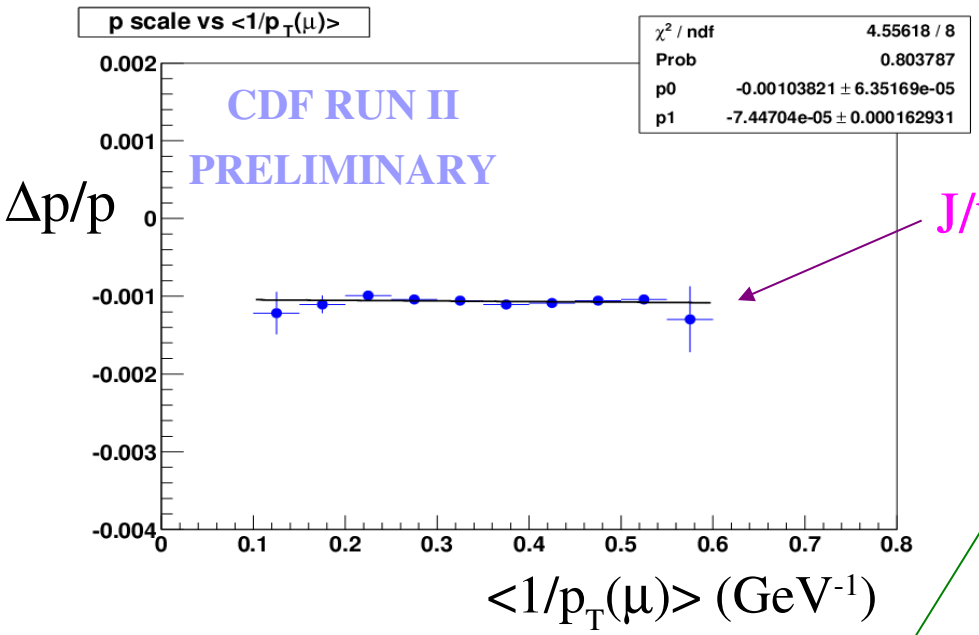
Final correction using difference in E/p from e^+ and e^-



* Alignment uncertainty taken to be difference in mass fits before and after final E/p-based correction : ~10 MeV/c^2

CDF Muon Momentum Calibration

Set momentum scale using J/ψ and upsilon decays to muons

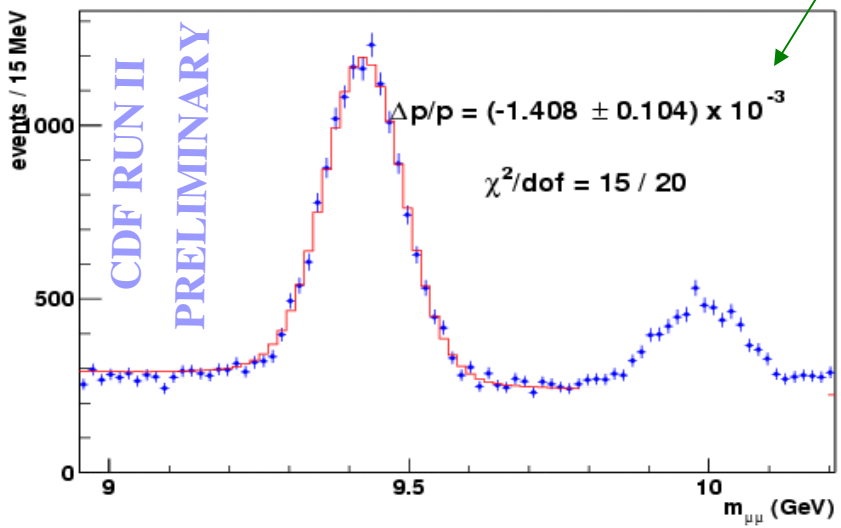


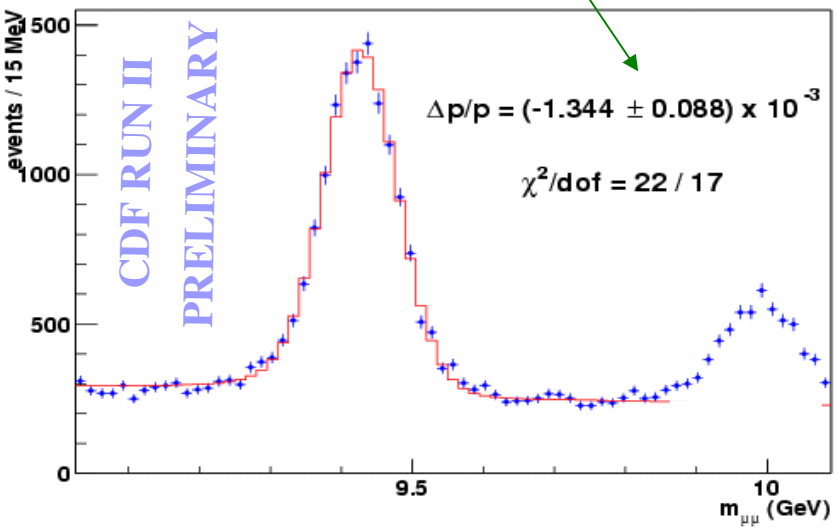
momentum determined to

3 parts in 10000: $\delta\, m_W = \pm 25$ MeV

J/ψ mass independent of muon momentum

Upsilon mass consistent using non-beam-constrained or beam-constrained tracks





Fast hit-level detector simulation

hit resolution, efficiency tuned with Υ

CDF Muon Momentum Calibration

Momentum scale has low systematic uncertainty:

Tracker is a linear device -- can use low momentum particles to set scale

Alignment uncertainties are indirect:

Arise only through fiducial differences between calibration and measurement samples

Direct effects of misalignments:

delta curvature = $a + b$ curvature + c curvature^2 + d curvature^3

a term cancels with charge symmetry

b term is momentum scale

c term cancels with charge symmetry

d term goes to zero at high momentum

Other factors:

* *Material understanding important for low-momentum resonances*

dE/dx energy loss, multiple scattering: affect scale extrapolation to high momentum and inferred hit resolution, respectively

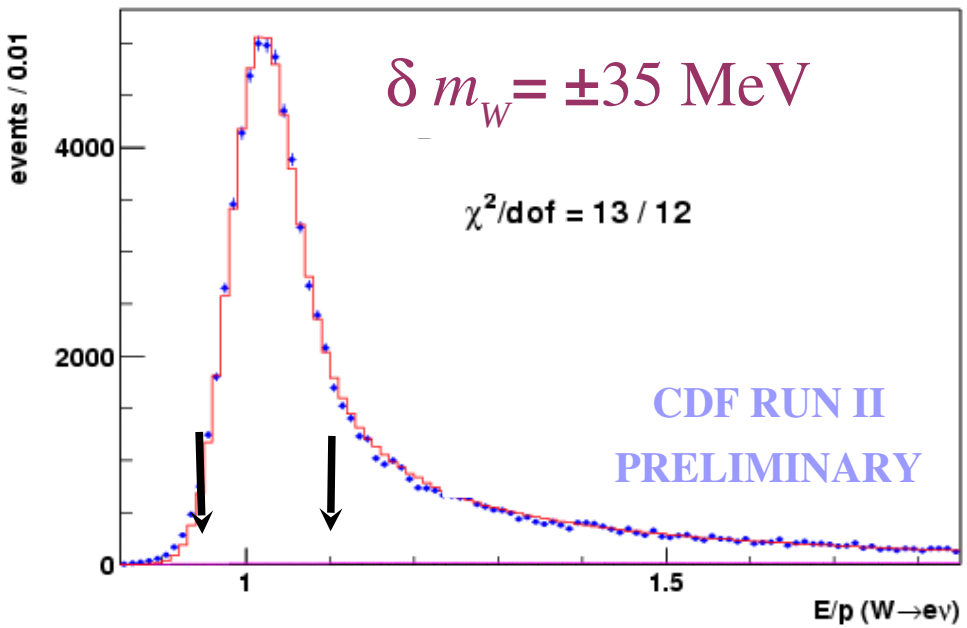
* *Beam constraint powerful, simulation needs accurate hit resolution and beam size*

CDF Electron Calibration

Use calibrated tracks to set calorimeter electromagnetic energy scale

E/p peak in $W \rightarrow e\nu$ events determines scale

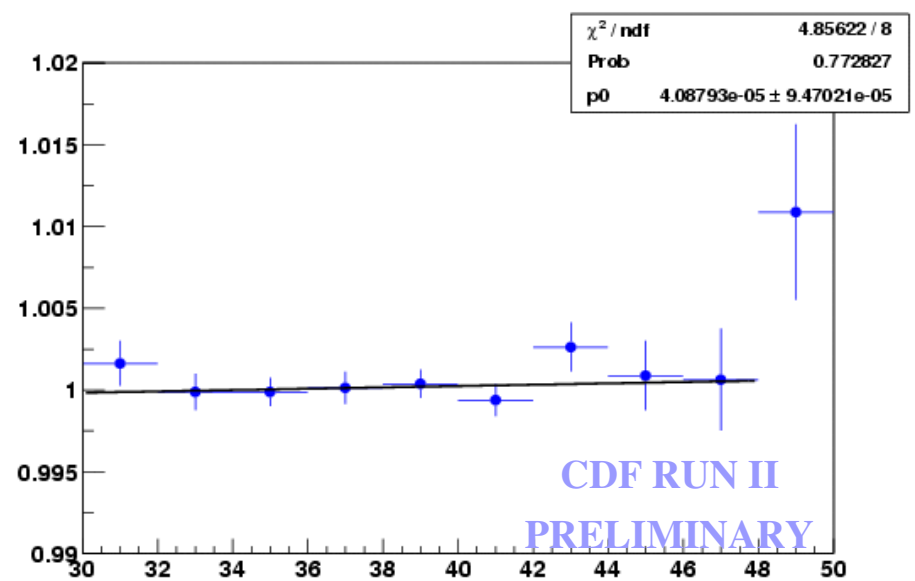
High statistics, similar energy distribution to measurement sample



Calorimeter has non-linear response

*Correct response using E/p distribution in bins of E_T

* Use both *W* and *Z* electrons



Linearity uncertainty affects mass measurement

* *difference between mean calibration E_T and mean measurement E_T*

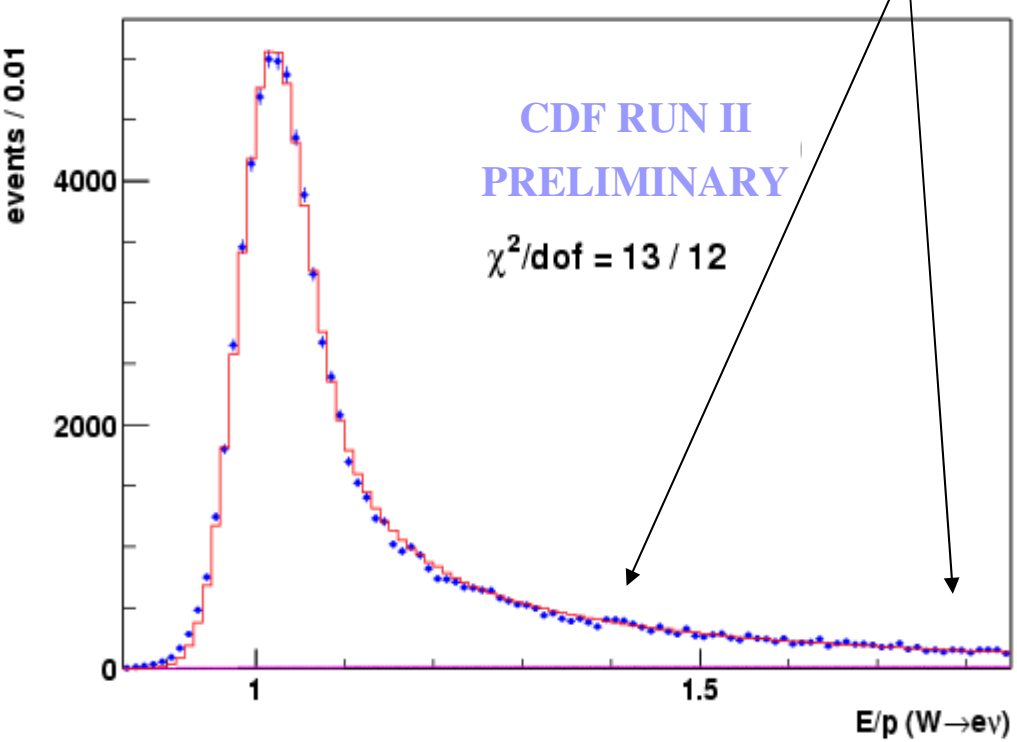
δ m_W= ±25 MeV

CDF Electron Calibration

Electron radiation in material affects position of *E/p* peak

* Significant amount of passive material (silicon) in CDF detector

Tune upstream passive material scale using tail of E/p distribution



Detailed fast simulation of radiation:

* *Look-up table for known passive material*
* *Model bremstrahlung and subsequent photon conversion*
* *Model energy loss in coil, hadronic leakage*

$\delta\, m_W = \pm\, 55$ MeV

Cross Checks

Use Z mass fits for tuning and cross-checks

Tune:

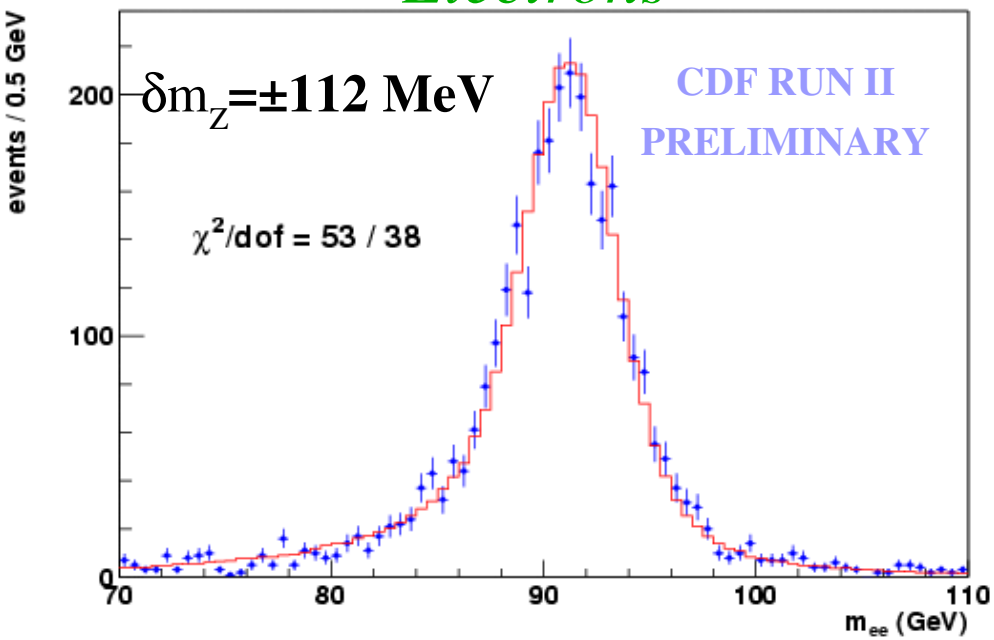
* COT hit resolution

Cross-check:

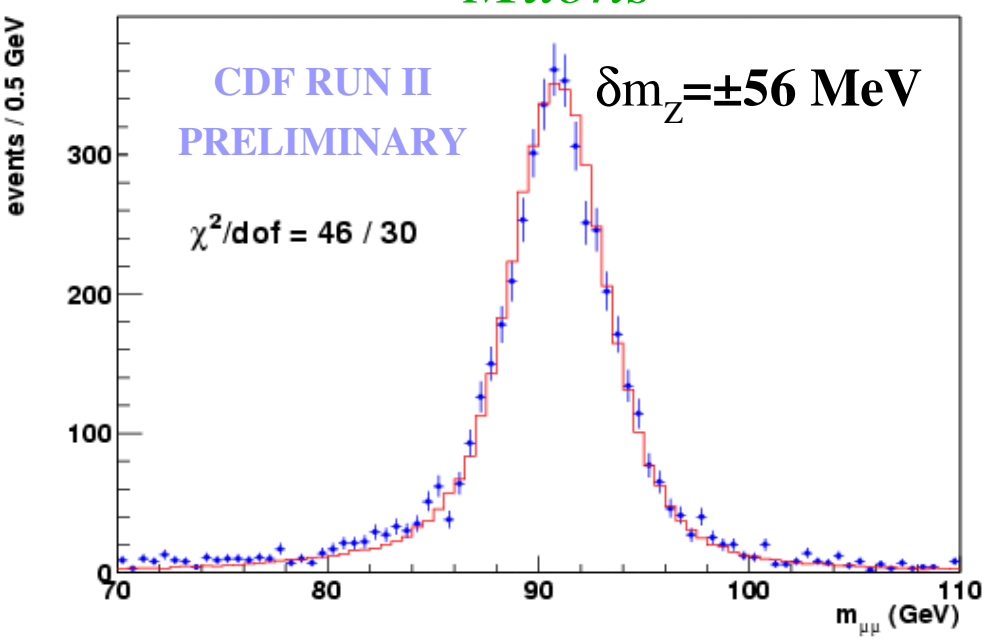
* Energy scales
* QED FSR

Need careful study of lineshapes

Electrons



Muons



M_{W+} - M_{W-} tests alignment biases (for $W \rightarrow \mu\nu$)

*** No statistically significant difference** *(after incorporating wire alignment)*

Summary

Muon momentum calibration cleaner than electron calibration

* *Minimal dependence on calorimeter (identification)*
* *Small energy loss and multiple scattering corrections for W's*
* *Tracker can be calibrated with any high statistics sample*

Important aspects to understand

* *Tracker alignment*
* *Tracker material*
* *Effect of beam constraint (if used)*